

# Influence of Environments of Deposition on the Inorganic Composition of Coals

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## Introduction

The mineral composition of coal is the result of physical, chemical and biological processes acting on the system from the time of peat accumulation, through burial and subsequent increase in rank, to the present. With respect to origin, inorganic constituents may be classified as: inherent (being derived from inorganic components within the peat-forming plants) or adventitious (being derived from outside the peat swamp and forming either during or after peat accumulation); and detrital (those transported into the peat swamp) or authigenic (those formed within the environment). Mackowsky (1) further differentiates between syngenetic minerals, formed during the accumulation of peat, and epigenetic minerals, which formed later.

In recent years considerable controversy has surrounded the origin of minerals in coal: the question is whether most of these materials are derived from inorganic substances originally contained within peat-forming plants (inherent), or from sources outside the peat swamp (detrital).

Studies of modern peat-forming environments have emphasized the importance of detrital influx (2,3), syngenetic formation of pyrite (4) and biogenic silica (2,5), and in-situ mixing with underlying sediments (2,6) to account for mineral constituents in coal. Within the peat environment certain unstable detrital clays may undergo alteration or dissolution (3,7); other clays, such as kaolinite, may form authigenically; and biogenic silica dissolves, possibly contributing to later authigenic mineralization (3,5). In coals, authigenic kaolinite formation along cleats is common (8,9). Clays may also form by alteration of volcanically-derived material (10). Opposing the concept of a major detrital input, Cecil and his co-workers (11,12) consider the major source of ash components to be the inorganic fraction of peat-forming plants, and total mineral content to be a function of the degree of peat degradation.

While this controversy still lingers, it appears that several origins are possible for minerals in peat and coal, including detrital influx, biogenic input, and precipitation either during or after peat accumulation, including some contribution from inorganic substances derived from plants. Various studies have attempted to relate inorganic composition to conditions existing at the time of peat accumulation. Pyrite has frequently been associated with marine and brackish peats (4,13), and the pyrite content of coal has been related to roof lithology (14,15). Clay assemblages of coals and underclays also have been related to depositional environment (9,16).

The purpose of this paper is to describe variability in the inorganic content of a single coal and attempt to explain the distribution of minerals in a framework of depositional environments. In western Pennsylvania, the Lower Kittanning seam provides an opportunity to study coal that was influenced by freshwater, brackish and marine conditions, as indicated by a previous study of the overlying shale (17). Several geologic controls are thought to have influenced deposition during this time: differential subsidence resulted in a thickening of sediments (and coal) towards the center of the basin; a basement high to the north of the field area may have supplied clastic material, adding

to a predominantly eastern sediment source; and active folds and variations in paleotopography may have also influenced sedimentation patterns (18).

#### Sampling and Methods

Forty-three channel samples of the Pennsylvanian-aged Lower Kittanning coal (Kittanning Formation, Allegheny Group) were collected in western Pennsylvania. Samples are representative of all three suggested depositional environments (Figure 1) and also of the increase in rank from high volatile bituminous in the west to low volatile bituminous in the southeast. Analyses included major and minor elements, total sulfur and sulfur forms, and low-temperature ashing. LTA's were obtained according to standard procedures (19). X-ray diffraction analysis of LTA's provided qualitative, quantitative (for quartz and pyrite), and semi-quantitative (for clays in the  $< 2 \mu\text{m}$  fraction) data using procedures modified from Russell and Rimmer (20). Kaolinite was quantified using infra-red spectroscopy. Mineral composition was also calculated by normative techniques modified from Pollack (21) and Given *et al.*, (22).

#### Results and Discussion

The major mineral components of this coal include quartz, pyrite (and marcasite), and clays (predominantly Kaolinite and illite/mica, with lesser amounts of expandable clays). Total mineral content (percent LTA) varies considerably across the basin, with very high ash contents occurring in the center of the basin and along sections of the Allegheny Front. To further understand these variations, individual mineral distributions were examined.

Pyrite distribution shows a definite basinal trend, with high pyrite contents occurring across the center of the basin (Figure 2). Whereas much of this area underlies marine and brackish roof rocks, the relationship is not perfect. Highest pyrite content appears to be most closely related to the eastern brackish zone. Factors influencing the distribution of sulfur in peat and coals include availability of iron and sulfate, and pH. Sulfate is thought to be introduced by marine and brackish waters (4). Recent work on pyrite distribution in the Florida Everglades (23) indicates highest pyrite content is associated with brackish environments rather than marine, and this has been related to the availability of iron. In freshwater, iron is transported in organic colloids which flocculate quickly upon entering brackish water, resulting in a higher availability of iron in brackish environments (24). pH is also a factor, as much of the pyrite appears to form as a by-product of sulfate-reducing bacteria (4). Compared to the more acidic freshwater environments, higher levels of microbial activity would occur in the neutral to basic pH conditions existing in marine or brackish waters. Pyrite content is therefore highest in areas that were influenced at least by brackish conditions.

The central part of the basin was experiencing more rapid subsidence than the margins, thus any marine influence would be greater in this area. Apparent discrepancies in the relationship between pyrite content and roof lithology may be explained on the basis of iron availability. (Data to be discussed later suggest a detrital influence towards the eastern margin of the basin, providing clay-rich sediments which may have contributed to the supply of iron). Other workers have also commented on this lack of correlation and suggest epigenetic pyrite formation along cleats and joints may be responsible (25). A third alternative is that the zone of maximum brackish and marine influence shifted during the history of the peat swamp.

Quartz content is highest in the north-central part of the basin, with isolated quartz-rich pods along the Allegheny Front. The origin of quartz in coal has been debated at length. Detrital quartz has been distinguished by many

authors (1,3) while other workers (11,12) believe much of this quartz is derived from silica originally contained within the plants. Petrographic observations of quartz in this coal revealed an association with attrital bands, suggesting a detrital origin. The distribution may be related to the basement high that existed to the north during this time (18). Transportation within the swamp of quartz-rich sediments derived from this high was possibly restricted by the baffling effect of vegetation, a phenomenon noted in modern swamps (2). In addition, lesser amounts of quartz may have been carried in from the east. Sediment derived from this latter source appears to have been predominantly clay. Comparable quartz distributions were noted in the underclay (26), thus the influence of in-situ mixing also exists.

Kaolinite is the major clay constituent of the coal and occurs in highest concentrations along the basin margins, with illite increasing towards the central part of the basin. Once again a similar distribution was noted in the underclays (26). Differential flocculation within the basin, together with chemical regrading of clays, could be used to explain this distribution. Holbrook (26) argues against this mechanism for the underclays on the basis of flocculation studies in modern environments, and suggests differential leaching related to variations in paleotopography may have been important. Another control could be the effect of peat chemistry on the clay assemblage. Kaolinite appears to be highest in freshwater environments where, under lower pH conditions, it would be the most stable clay mineral. Thus, in these areas not only could kaolinite be detrital, but also the product of clay alteration and authigenesis. The presence of high-temperature polytypes suggest a detrital origin for illite/mica in the Lower Kittanning coal and underclay, as discussed by Davis et al. (3) and Holbrook (26). Detrital illite/mica would be better preserved in more basinward areas.

One additional control on the clay mineral assemblage could be rank. With the increase in rank exhibited by this coal, certain diagenetic changes might be expected. No consistent trends in mineralogy were observed, however a general lack of smectite and highly-expandable clays (which can be seen in lower rank coals) was noted. This could be related to rank, or be a function of provenance.

#### Summary

The distribution of minerals within the Lower Kittanning coal can be related to depositional environments. Total mineral content varies considerably across the basin, and variations can be explained by examining the distributions of individual minerals.

Pyrite content is controlled by availability of sulfate and iron, and pH. Highest concentrations are seen towards the center of the basin where subsidence was more rapid and marine and brackish influences (affecting sulfate availability and pH) were felt during and after peat accumulation. Iron availability may have been associated with the transport of organic colloids or clay into the basin.

Quartz appears to be limited to the northern part of the field area and isolated areas along the Allegheny Front. It is suggested that quartz-rich sediments were derived from a positive area to the north. Much of the sediment brought in from the east appears to have been clay-rich.

The chemistry of the peat may have had a strong influence on clay mineral assemblage. Kaolinite may have been both detrital and authigenic, whereas illite/mica appears to be detrital. Rank has had little effect on the overall clay assemblage.

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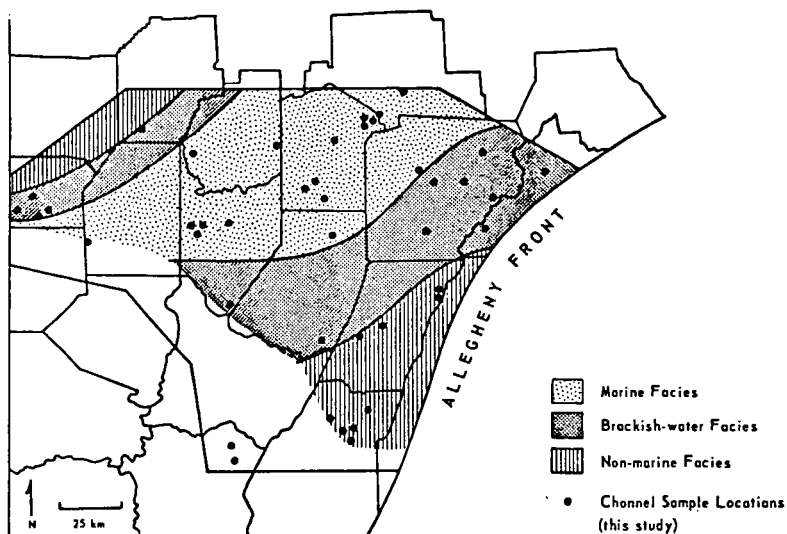


FIGURE 1. DISTRIBUTION OF SAMPLES IN WESTERN PENNSYLVANIA IN RELATION TO SUGGESTED ENVIRONMENTS OF DEPOSITION FOR THE OVERLYING SHALE

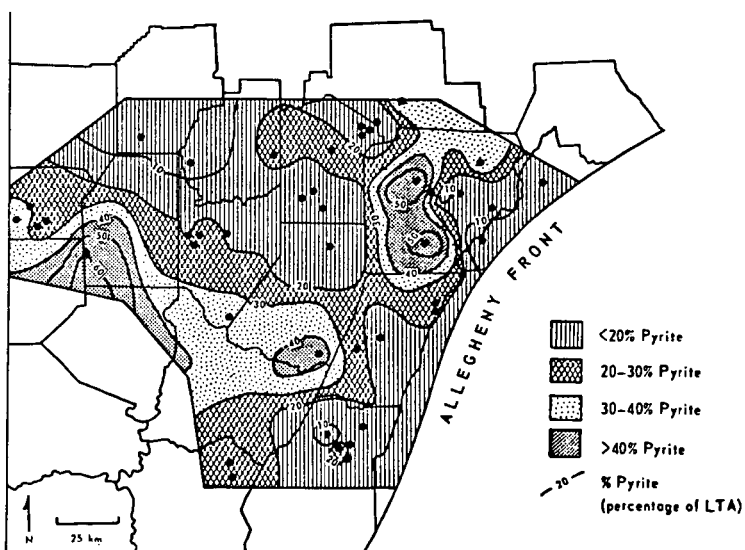


FIGURE 2. LATERAL VARIABILITY IN PYRITE CONTENT (LTA BASIS), AS DETERMINED BY X-RAY DIFFRACTION ANALYSIS